Extended Tables and Figures for

Climate mitigation potentials of teleworking are sensitive to changes in lifestyle and workplace rather than ICT usage

https://www.pnas.org/doi/10.1073/pnas.2304099120

Yanqiu Tao[a], Longqi Yang[b*], Sonia Jaffe[b], Fereshteh Amini[b], Peter Bergen[b], Brent Hecht[b], Fengqi You[a,c,d*]

[a] Systems Engineering, Cornell University, Ithaca, NY, 14853, USA

[b] Microsoft Corporation, Redmond, WA, 98052, USA

[c] Robert Frederick Smith School of Chemical and Biomolecular Engineering, Cornell University, Ithaca, NY, 14853, USA

[d] Cornell Atkinson Center for Sustainability, 340 Tower Road, Cornell University, Ithaca, NY, 14853, USA

* **Email:** longqi.yang@microsoft.com; fengqi.you@cornell.edu

Extended methods

Life cycle inventory for residential energy use:

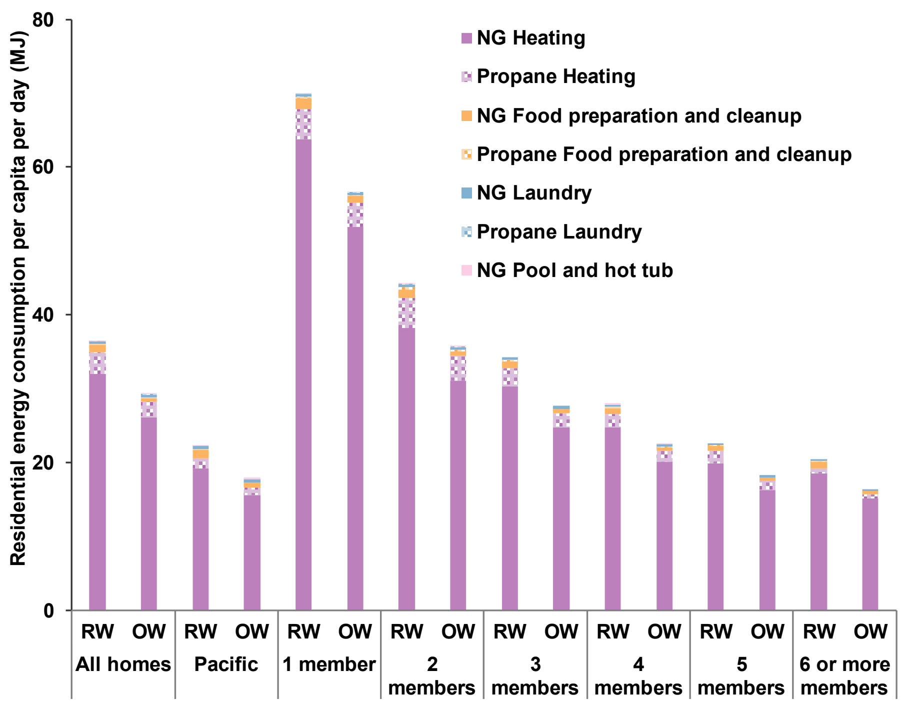

Fig. S1. Average residential energy consumption for remote and onsite work with 1-6 members in the household.

Table S1. Time use and energy use by work mode and home energy end use for the Pacific region (*1, 2*).

Aggregated home energy end use	Time use (hour)		Natural gas (MJ)		Propane (MJ)		Electricity (kWh)		Assumption
	RW	OW	RW	OW	RW	OW	RW	OW	
Heating	15.88	12.93	19.18	15.62	1.38	1.01	2.17	0.18	Allocated to the time when people is at home
Cooling	15.88	12.93					0.18	0.14	
Air conditioning	15.88	12.93					0.67	0.55	
Humidifying and dehumidifying	15.88	12.93					0.07	0.05	
Lighting	15.88	12.93					0.85	0.51	
Laundry			0.45	0.45			0.43	0.43	Assume same
Refrigerators	24.00	24.00					0.89	0.89	24-hour operation
Food preparation	0.43	0.23	1.12	0.61	0.10	0.08	0.28	0.15	Allocated to the time when people do food preparation and cleanup
TVs	0.43	0.23					0.41	0.38	Allocated to the time when people watch TV
Pool and hot hub	0.43	0.23	0.19	0.23			0.10	0.13	Allocated to the time when people relax

Life cycle inventory for office energy use:

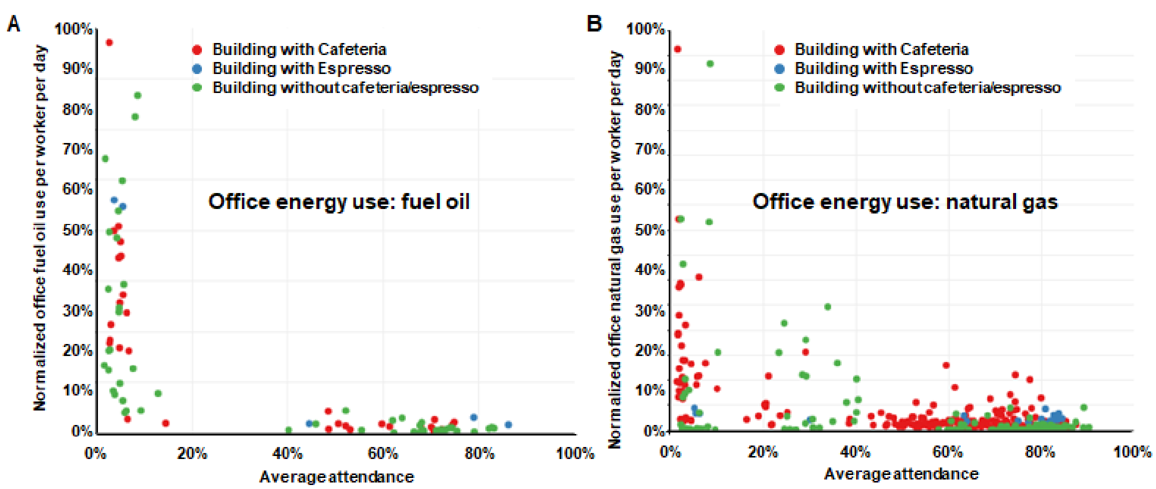

Fig. S2. Nonlinear relationships between building attendance, the existence of a cafeteria, and office energy use for (A) fuel oil and (B) natural gas.

Table S2. Results of model fitting for nonlinear relationships between building attendance, building headcount, the existence of a cafeteria, and office energy use.

Coefficients	Estimate	Std. Error	t value	Pr(>|t|)
Intercept (*a*)	3.28	0.081	40.49	< 2E-16
Log(%Building attendance) (*b*)	-0.92	0.027	-33.60	< 2E-16
Dummy variable of Café (*c*)	0.24	0.062	3.81	0.00016
Headcount (*d*)	-3.30E-04	6.64E-05	-4.97	1.03E-06
$Energy\ use = e^{a+c\cdot Cafe\_dummy+d\cdot Headcount}\cdot(\%Building\ attendance)^{b}$				

Table S3. Methodology for calculating non-occupancy and occupancy-related energy use. The parameter *a* indicates the number of people sharing one seat.

Scenario	Non-occupancy-related energy use (*x* per seat per workday)	Occupancy-related energy use (*y* per capita per day)	Total office energy use (*z*)
RW (OW0)	0	0	$z=0$
OW (OW5)	$5\cdot x$	$5\cdot y$	$z=5\cdot(x+y)$
HW (OW1)	$5\cdot\frac{1}{a}\cdot x$	$1\cdot y$	$z=5\cdot\frac{1}{a}\cdot x+1\cdot y$
HW (OW2)		$2\cdot y$	$z=5\cdot\frac{1}{a}\cdot x+2\cdot y$
HW (OW3)		$3\cdot y$	$z=5\cdot\frac{1}{a}\cdot x+3\cdot y$
HW (OW4)		$4\cdot y$	$z=5\cdot\frac{1}{a}\cdot x+4\cdot y$

Life cycle impact assessment:

Table S4. Characterization factors collected from Ecoinvent database (version 3.9.1) (*3*).

Item	Ecoinvent process	Region	Amount	Unit	GWP100 (IPCC 2013; kg CO2 eq.)
Propane production	market for propane	GLO	1	kg	1.12
Home heating, natural gas	market group for heat, central or small-scale, natural gas	GLO	1	MJ	0.079
Home and office electricity use	market group for electricity, low voltage	US-WECC	1	kWh	0.38
Transport, small size ICEV	market for transport, passenger car, small size, petrol, EURO 5	GLO	1	km	0.30
Transport, medium size ICEV	market for transport, passenger car, medium size, petrol, EURO 5	GLO	1	km	0.37
Transport, large size ICEV	market for transport, passenger car, large size, petrol, EURO 5	GLO	1	km	0.44
Transport, train	market for transport, passenger train	GLO	1	person*km	0.075
Transport, bus	market for transport, regular bus	RoW	1	person*km	0.12
Transport, EV	transport, passenger car, electric	GLO	1	km	0.23
Office heating, light fuel oil	heat production, light fuel oil, at boiler 100kW condensing, non-modulating	RoW	1		0.095
Office heating, natural gas	heat production, natural gas, at boiler condensing modulating <100kW	RoW	1	MJ	0.072
Transport, airplane	market for transport, passenger aircraft, unspecified	GLO	1	person*km	0.12
Transport, bicycle	market for transport, passenger, bicycle	GLO	1	person*km	0.012
Transport, motorcycle	market for transport, passenger, motor scooter	GLO	1	person*km	0.17

Sensitivity analysis:

Table S5. Modified emission factors for projected EV scenarios (*4*).

	Emission factors for electricity (kg CO_2 eq./kWh)				EV transport emission factors (kg CO_2 eq./mile)			
US regions	**2023**	**2030**	**2040**	**2050**	**2023**	**2030**	**2040**	**2050**
US average	0.364	0.193	0.163	0.145	0.203	0.148	0.139	0.133
New England	0.190	0.096	0.096	0.079	0.147	0.117	0.117	0.112
Middle Atlantic	0.362	0.273	0.222	0.198	0.202	0.174	0.157	0.150
East North Central	0.429	0.215	0.202	0.172	0.224	0.155	0.151	0.141
West North Central	0.456	0.163	0.160	0.145	0.232	0.139	0.137	0.133
South Atlantic	0.341	0.188	0.172	0.140	0.196	0.146	0.141	0.131
East South Central	0.511	0.276	0.226	0.197	0.250	0.175	0.159	0.149
West South Central	0.344	0.186	0.148	0.144	0.196	0.146	0.134	0.132
Mountain	0.504	0.209	0.133	0.143	0.248	0.153	0.129	0.132
Pacific	0.122	0.099	0.072	0.058	0.125	0.118	0.109	0.105

Extended results and discussion

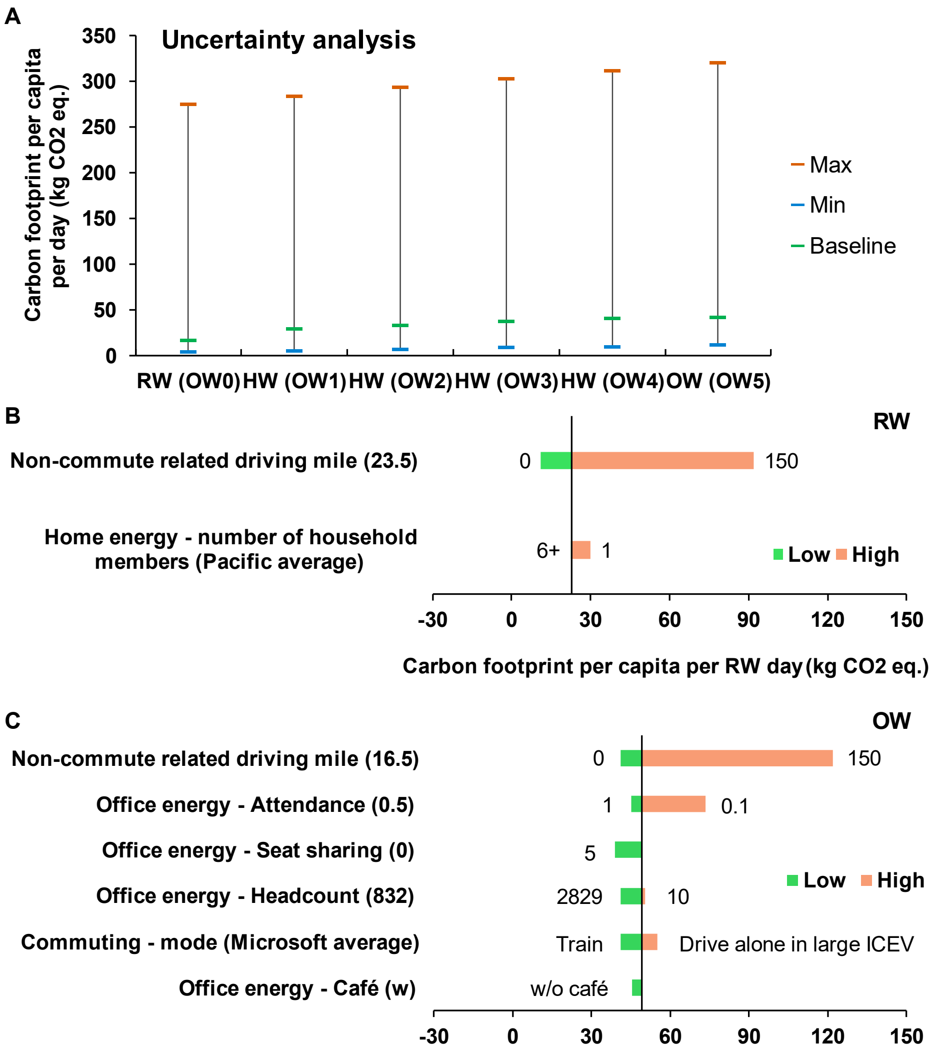

Fig. S3. Variation in the GHG emissions of the six remote work scenarios and sensitivity analyses. (A) uncertainty analysis, (B) sensitivity analysis for the fully remote work scenario, (C) sensitivity analysis for the fully onsite work scenario.

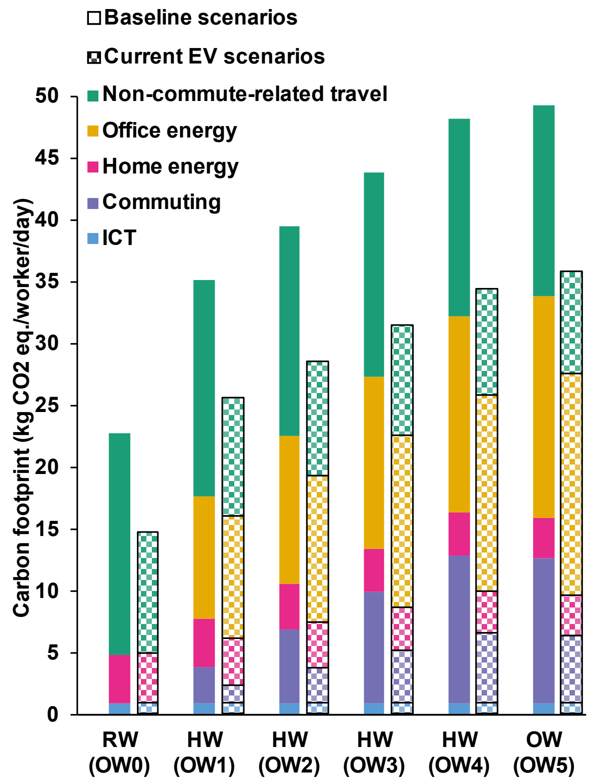

Fig. S4. Sensitivity analysis of electric vehicle (EV) use in the life cycle stage of commuting and non-commute-related travel. Breakdown of life cycle carbon footprint for ICT, commuting, home energy, office energy, and non-commute-related travel for all six baseline remote work scenarios and six current EV scenarios are presented in the figure. In the current EV scenarios, we assume that EV are used exclusively as passenger car for both commuting and non-commute-related travel with default setting of global power supply from the Ecoinvent database. Acronyms: electric vehicle (EV), information and communication technology (ICT), remote worker (RW), hybrid worker (HW), onsite work/onsite worker (OW).

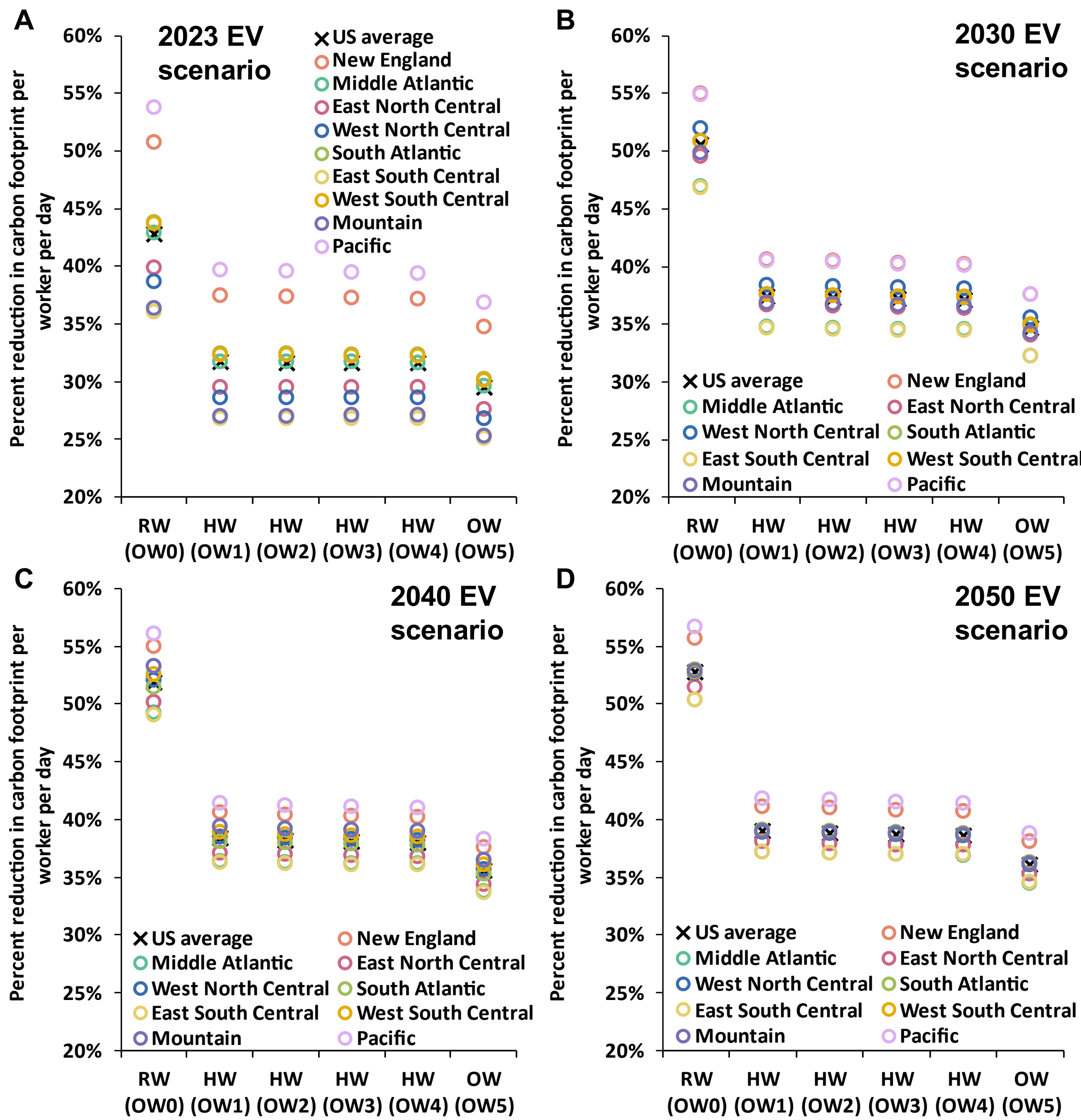

Fig. S5. Temporal and spatial variation in electric vehicle use in the life cycle stage of commuting and non-commute-related travel. Percent reduction in carbon footprint per worker per day for six projected EV scenarios in 2023 (A), 2030 (B), 2040 (C), and 2050 (D), relative to their corresponding 2020 EV scenarios. Acronyms: electric vehicle (EV), remote worker (RW), hybrid worker (HW), onsite work/onsite worker (OW), United States (US).

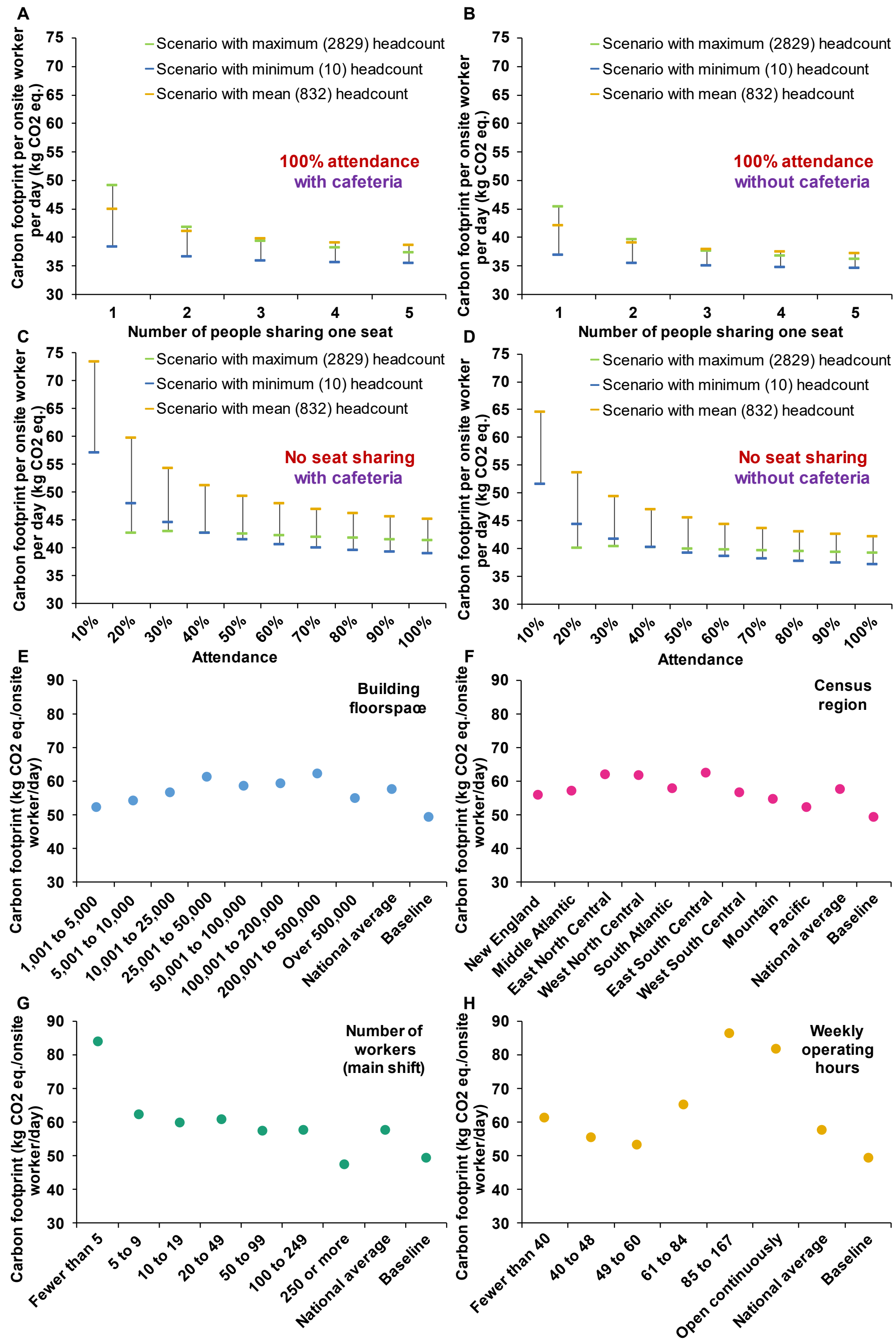

Fig. S6. Sensitivity analyses on the variables related to office energy use. (A-B) show variation in life cycle carbon footprint per onsite worker per day to seat sharing and building headcount, with respect to the assumption of full building attendance. The assumption regarding the existence of cafeteria differs for (A) with cafeteria (B) without cafeteria. (C-D) show variation in life cycle carbon footprint per onsite worker per day to building attendance and headcount, with respect to the baseline assumption of no seat sharing. The assumption regarding the existence of cafeteria differs for (C) with cafeteria (D) without cafeteria. (E-H) show variation in life cycle carbon footprint per onsite worker per day to (E) building floorspace, (F) census region, (G) number of workers during the main shift, and (H) weekly operating hours, based on the 2018 CBECS data.

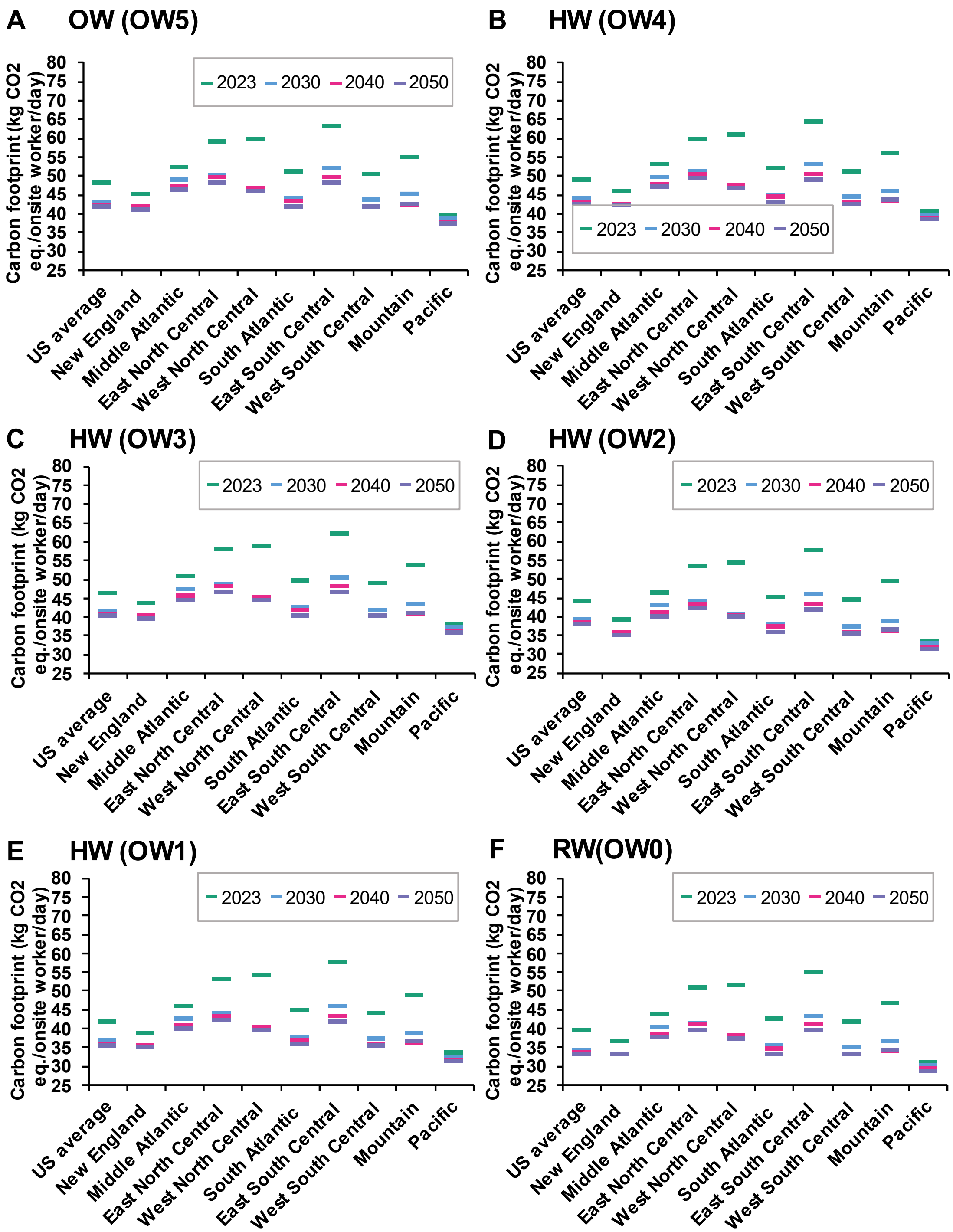

Fig. S7. Sensitivity analyses and temporal and spatial variation of the variables related to office energy use. Life cycle carbon footprint per onsite worker per day for the six scenarios of (A) OW (OW5), (B) HW (OW4), (C) HW (OW3), (D) HW (OW2), (E) HW (OW1), and (F) RW(OW0) according to the projected emissions of US census regions. Acronyms: United States (US).

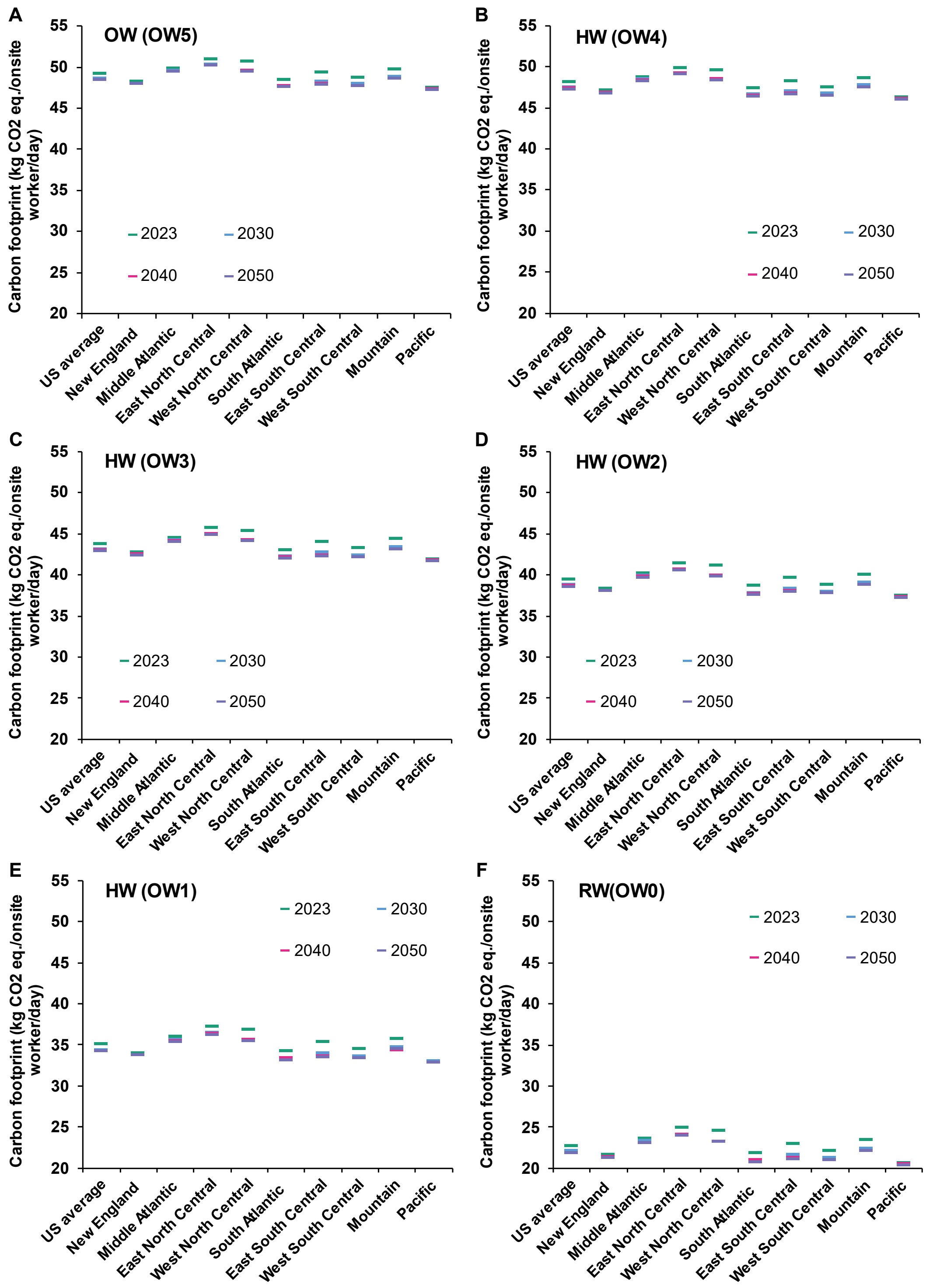

Fig. S8. Temporal and spatial variation of the variables related to home energy use. Life cycle carbon footprint per onsite worker per day, according to the projected emissions of US power grids in (A) 2030, (B) 2040, and (C) 2050. (D-F) show temporal and spatial variation in life cycle carbon footprint per remote worker per day for the six scenarios of (A) OW (OW5), (B) HW (OW4), (C) HW (OW3), (D) HW (OW2), (E) HW (OW1), and (F) RW(OW0) according to the projected emissions of US census regions. Acronyms: remote worker (RW), onsite work/onsite worker (OW), United States (US).

SI References

1. 2015 American Time Use Survey (Bureau of Labor Statistics, 2015).
2. 2015 Residential Energy Consumption Survey (RECS) Data (U.S. Energy Information Administration) [09/11/2021].
3. G. Wernet, C. Bauer, B. Steubing, J. Reinhard, E. Moreno-Ruiz, B. Weidema, The ecoinvent database version 3 (part I): overview and methodology. *The International Journal of Life Cycle Assessment* **21**, 1218-1230 (2016).
4. A. Lal, F. You, PEESEgroup/LIB_Supply-Chain: EV Battery Supply Chain (1.0) *Zenodo*, (2023).